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Parametrical investigation of the effect of dead (reference) state on energy and exergy utilization efficiencies of residential–commercial sectors: A review and an application

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Abstract

For the first time, energy and exergy utilization efficiencies in a residential–commercial sector are investigated from the varying dead (reference) state viewpoint in this study. In this regard, the studies performed in this field are reviewed first. A parametric study is then conducted to study how varying dead state temperatures ranging from 0 to 25 °C will effect energy and exergy utilization efficiencies in the residential–commercial sector. Next, a case study of the Turkish residential–commercial sector (TRCS), which includes space heating, water heating, cooking and electrical appliances, is also given to illustrate these variations based on the actual data in the year of 2003. Finally, the results obtained are discussed. The energy efficiency values for the TRCS are found from 51.95 to 80.82% and the exergy efficiency values for that are obtained from 8.11 to 11.92% at varying dead state temperatures from 25 to 0 °C. It is anticipated that the results obtained will provide the investigators with knowledge about how effectively and efficiently a country uses its natural resources. This knowledge is also needed for identifying energy improvement potential as well as for dictating the energy strategies of a country or a society.

Keywords: Dead state; Energy utilization; Exergy; Efficiencies; Reference state; Residential sector; Turkey

Abbreviations: RCS, residential–commercial sector; TRCS, Turkish residential–commercial sector; SH, space heating.

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Nomenclature

C	specific heat (kJ/kg K)
D	diameter (m)
E	energy (kJ)
$\dot{E}$	energy rate (kW)
ex	specific exergy (kJ/kg)
Ex	exergy (kJ)
$\dot{\mathrm{E}}\mathrm{x}$	exergy rate (kW)
h	specific enthalpy (kJ/kg)
I	irreversibility, exergy consumption (kJ)
$\dot{I}$	irreversibility rate, exergy consumption rate (kW)
$I\dot{P}$	improvement potential rate for exergy (kW)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (Pa)
s	specific entropy (kJ/kgK)
$\dot{S}$	entropy rate (kW)
T	temperature (K)
W	work (kJ)
$\dot{W}$	work rate or power (kW)
e	share of electrical energy use
f	share of fuel use
ke	kinetic energy (kJ/kg)
Q	heat transfer (kJ)
q	quality factor of an energy carrier

Greek letters

ε_1	energy (first-law) efficiency (%)
ε_2	exergy (second-law) efficiency (%)
γ	exergy grade function

Indices

0	dead state or reference environment
c	cooking, component
d	direct
e	electrical
f	fuel, first
h	heating
ke	kinetic energy
l	lighting
o	overall
p	product
Q	heat

or	overall residential
orc	overall residential–commercial
r	renewable, region
rc	residential–commercial
s	stream
sh	space heating

Contents

1. Introduction

The energy balance is the basic method of process investigation. It makes the energy analysis possible, points at the needs to improve the process, is the key to optimization and is also the basis to developing the exergy balance. Analysis of the energy balance results

would disclose the efficiency of energy utilization in particular parts of the process and allow comparing the efficiency and the process parameters with the currently achievable values in the most modern installations. The analysis uses the concept of energy and its conservation. The forms of energy can be expressed as enthalpy, internal energy, chemical energy, work, heat, electricity, etc. They will establish also the priority of the processes requiring consideration, either because of their excessive energy consumption or because of their particularly low efficiency [1].

The exergy of an energy form or a substance is a measure of its usefulness or quality or potential to cause change [2]. Exergy is defined as the maximum work, which can be produced by a system or a flow of matter or energy and it comes to equilibrium with a specified reference environment (dead state). Unlike energy, exergy is conserved only during ideal processes and destroyed due to irreversibilities in real processes [3].

The exergy concept was introduced to overcome limitations of the energy analysis. The exergy expresses the practical value of any substance (or any field matter, e.g. a heat radiation), and is defined as a maximum ability of this substance to perform work relative to human environment. In the background of the exergy concept it is assumed that all the common human environment components, available for free in the unlimited amounts, are practically worthless and their exergy is zero. However, any matter at parameters (e.g. pressure, temperature, composition) being not in equilibrium with the environment, has a certain practical value, which can be measured as its potential to work and is expressed as the exergy [4].

Exergy is a measure of the maximum capacity of a system to perform useful work as it proceeds to a specified final state in equilibrium with its surroundings. The available work that can be extracted from an energy source depends on the state of the source's surroundings. The greater the difference between the energy source and its surroundings, the greater the capacity to extract work from the system.

According to Wall [5], exergy is the maximum amount of work that can be extracted from a contrast of any kind, e.g. a mineral deposit or sunlight. Exergy is often defined as the maximum work potential of a material or of a form of energy in relation to its environment, i.e. a dead reference state. Usually, the dead state is the ambient temperature and pressure, e.g. 25 °C and 1 atm. However, the Earth is not in a state of thermodynamic equilibrium; indeed, it is far from an equilibrium state. The temperature varies from place to place. Pressure and chemical conditions also vary around the globe. Other important factors are the deposits of fossil fuels and the existence of oxygen in the atmosphere, as described above, which build-up a huge thermodynamic potential. Thus, the Earth and the environment are in a state far from thermodynamic equilibrium. However, for the life processes the sustainability of this state is of an essential importance.

The exergy analysis is the modern thermodynamic method used as an advanced tool for engineering process evaluation [6]. Whereas the energy analysis is based on the First-Law of Thermodynamics, the exergy analysis is based on both the First and the Second Laws of Thermodynamics. Both analyses utilize also the material balance for the considered system. Analysis and optimization of any physical or chemical process, using the energy and exergy concepts, can provide the two different views of the considered process. The main purpose of exergy analysis to discover the causes and quantitatively estimate the magnitude of the imperfection of a thermal or chemical process. Exergy analysis leads to a better understanding of the influence of thermodynamic phenomena on the process effectiveness, comparison of the importance of different thermodynamic factors,

and the determination of the most effective ways of improving the process under consideration [7].

Some energy and exergy values depend on the intensive properties of the dead state. Consequently, the results of energy and exergy analyses are generally sensitive to variations in these properties. Before energy and exergy analyses can be applied with confidence to engineering systems, the significance of the delicateness of energy- and exergy-analysis results to reasonable variations in dead state properties must be assessed. Actually, only a few analyses of dead state variations have been reported. Wepfer and Gaggioli [8] have pointed out that exergy analyses of chemical plants are often relatively insensitive to variations in dead state temperature and pressure (T_o and P_o). Many have assumed that small and reasonable changes in dead state properties have little effect on the performance of a given system.

Rosen and Dincer studied on the effect of varying dead state in thermal systems. This study dealt with the effects on the results of energy and exergy analyses of variations in dead state properties, and involved two main tasks: (i) Examination of the sensitivities of energy and exergy values to the choice of the dead state properties. (ii) Analysis of the sensitivities of the results of energy and exergy analyses of complex systems to the choice of dead state properties. A case study of a coal-fired electrical generating station was considered to illustrate the actual influences. The results indicated that the sensitivities of energy and exergy values and the results of energy and exergy analyses to reasonable variations in dead state properties were sufficiently small that the findings, conclusions and recommendations based on such analyses usually were not significantly affected by the property variations [9].

Ozgener et al. [10] performed a parametric study using the actual operational data to investigate how varying dead state temperatures from 0 to 25 °C affected the energy and exergy efficiencies of the Balcova geothermal district heating system in Izmir, Turkey and developed two significant correlations (with a correlation coefficient of 0.99) that could be used for predicting the efficiencies.

The method of exergy analysis has been applied to a wide variety of thermal and thermo chemical systems. A particular thermo dynamical system is the society, for example, of a country or a region according to Erteswag (2001) [11].

The energy utilization of a country can be evaluated using exergy analysis to gain insights into its efficiency [12]. The first one was applied by Reistad to the US in 1970, published in 1975 [11,13], while the most comprehensive one in terms of years appears to be Ayres et al.'s analysis of the US between 1900 and 1998, published in [14]. The approaches used to perform the exergy analyses of countries may be grouped into three types: First two approaches; namely Reistad's approach and Wall's approach, as denoted by Ertesvag [11] and the last one Scuiba's approach [15,16].

The first approach considers flows of energy carriers for energy use, while the second one takes into account all types of energy and material flows (see Ref. [16] for more detail). Reistad's approach is followed in the analyses of Finland [17], Canada [18], Brazil [19], the Organization for Economic Co-operation and Development (OECD) countries, non-OECD countries, and the world [20], England [21], and Saudi Arabia [22–25]. Besides these, the analyses of Sweden [26–28], Ghana [29], Japan [30], Italy [31] and Norway [32] follow Wall's approach. In addition, a new approach, the so-called extended-exergy accounting method, was introduced by Sciubba [31] and applied to the Italian society 1996 by Milia and Sciubba [15,16].

As for studies performed on Turkey's sectoral (commercial, residential, industrial and transportation) energy and exergy analyses, to date, 13 studies [12,33–44] were realized. Of these, 12 [12,33–43] followed Reistad's approach [13].

Developing countries have 80% of the world's population, but consume only 30% of global commercial energy. As energy consumption rises with increases in population and living standards, awareness is growing about the environmental costs of energy and the need to expand access to energy in new ways. Residential and commercial buildings account for about one-third of total final energy use in most countries. Residential energy consumption depends mainly on the available amounts of local resources, which are closely connected with the present rural economy and living standards [45]. Fig. 1 illustrates energy and exergy flows in a macro system for the residential–commercial sector (RCS). Space heating is the most important energy used in residential–commercial buildings for most countries. The importance of space heating changes according to local weather conditions. The amount of energy used for space heating is different widely among countries due to differences indoor heating comfort, heating equipment and insulation. Water heating and cooking also account for an important part of residential demand, with its fuel preferences tight connected to the space-heating system. The fastest raising end-use in buildings is electric appliances.

Very limited studies have been undertaken to perform a parametrical study on the effect of dead state on energy and exergy efficiencies of thermal systems [9,10]. However, no any parametrical study on the effect of varying dead state on the energy and exergy utilization efficiencies of RCSs-based on the actual data has appeared in the literature to the best of the authors' knowledge. The methodology used in this study for analyzing Turkey's energy and exergy use in the RCS is similar to that of Rosen and Dincer [12], who used Reistad's approach [13] with several minor differences. In this regard, dead state definition is described first. Thermodynamic relations used to perform energy and exergy analyses are

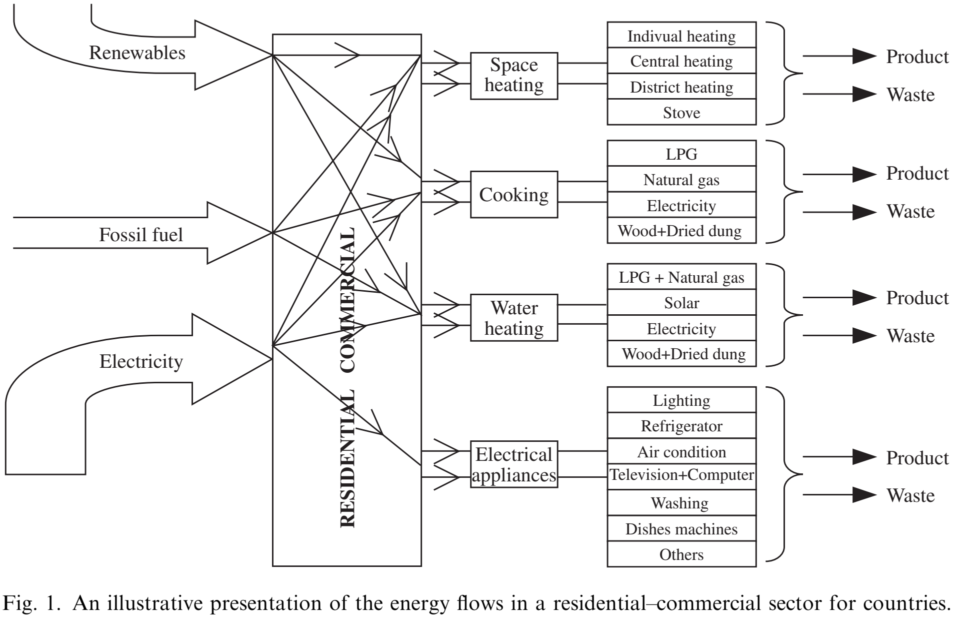

Fig. 1. An illustrative presentation of the energy flows in a residential–commercial sector for countries.

given then. Next, the polynomial relations developed for the RCS and its subsectors, such as water heating, space heating cooking and electrical appliances are presented. Finally, these relations are applied to the Turkish residential–commercial sector (TRCS), while the results obtained are discussed.

2. Dead (reference) state

Dead state definitions of exergy analysis are studied by Krakow [46]. In his study, the following was reported: Exergy analysis is an implicit comparison of the performance of real thermal systems with the performance of ideal, reversible thermal systems. Systems must have basic similarities and equivalent boundary conditions to be comparable. Thermal power and refrigeration systems are considered to operate between high-temperature and low temperature reservoirs. Effective reservoirs temperature and specific humidity are defined to enable boundary conditions for real and ideal systems to be considered equivalent.

It should be noticed that exergy is always evaluated with respect to a reference environment (i.e. dead state). When a system is in equilibrium with the environment, the state of the system is called the *dead state* due to the fact that the exergy is zero. At the dead state, the conditions of mechanical, thermal, and chemical equilibrium between the system and the environment are satisfied: the pressure, temperature, and chemical potentials of the system equal those of the environment, respectively. In addition, the system has no motion or elevation relative to coordinates in the environment. Under these conditions, there is neither possibility of a spontaneous change within the system or the environment nor an interaction between them. The value of exergy is zero. Another type of equilibrium between the system and environment can be identified. This is a restricted form of equilibrium, where only the conditions of mechanical and thermal equilibrium (thermo-mechanical equilibrium) must be satisfied. Such state is called the *restricted dead state*. At the restricted dead state, the fixed quantity of matter under consideration is imagined to be sealed in an envelope impervious to mass flow, at zero velocity and elevation relative to coordinates in the environment, and at the temperature $T0$ and pressure $P0$ taken often as $25\,^{\circ}\mathrm{C}$ and 1 atm [46].

Ideal system is a reversible cycle that is one consisting of reversible processes only. The efficiency of an engine operating on a reversible cycle can be shown to be at the maximum, i.e., greater than that of any engine operation on an irreversible cycle can be shown to be at the maximum, i.e., greater than that of any refrigeration system operating on an irreversible cycle. It follows that the efficiencies of all reversible engine cycles are equal and are the maximum possible, and the COP's of all reversible-cycle refrigeration systems are equal and are the maximum possible. Three key system parameters are taken into account for an explicit comparison of ideal and real systems. The relationship between these fundamental parameters is the basis for the severe definition of the dead state temperature. The three fundamental parameters for ideal systems are second-law efficiency, irreversibility, and reversible work. The three corresponding fundamental parameters for real systems are exergy efficiency, exergy destruction, and reversible work. Corresponding parameters (second-law efficiency and exergy efficiency, irreversibility, and exergy destruction) are essentially equivalent. The different terminology used is to indicate that the method of calculation is related to ideal systems or to real systems. The concept of reversible work does not have a suitable alternative term that is applicable to engines and

refrigeration systems, is therefore differentiated by refrigeration systems, and is therefore differentiated by subscripting only when it is related to ideal systems. The equivalence between ideal and real systems in depends on the equivalence of corresponding parameters. There are two basic differences between ideal and real systems. First, the heat capacities of the source and sink of ideal systems are infinite, but the heat capacities of the source and sink of real systems are finite. Second, the temperatures of the source and sink of ideal systems are constant, but the temperatures of the source and sink of real systems are variable. Second-law efficiency and exergy efficiency areimplicit comparisons of real system performance with ideal system performance. Irreversibility and exergy destruction are also implicit comparisons of real system performance with ideal system performance. The reservoirs of real systems have finite heat capacities and variable temperatures. Exergy analysis is an implicit comparison of the performance of real thermal systems with the performance of ideal systems. Ideal and real systems are regarded to operate between high-temperature and low-temperature reservoirs. Ideal systems are considered to be irreversible, although some of their components may be considered reversible [45].

3. Analysis

This section covers some of the key aspects of thermodynamics in terms of energy and exergy used in the modeling [12,20,25,39,40,47].

3.1. General relations used in the modeling

For a general steady state, steady-flow process, the four balance equations are applied to find the work and heat interactions, the rate of exergy decrease, the rate of irreversibility, the energy and exergy efficiencies [47–49].

The mass balance equation can be expressed in the rate form as

$$\sum \dot{m}_{\mathrm{in}} = \sum \dot{m}_{\mathrm{out}} \tag{1}$$

where, $\dot{m}$ is the mass flow rate, and the subscript in stands for inlet and out for outlet.

The general energy balance can be expressed as

$$\sum \dot{E}_{\mathrm{in}} = \sum \dot{E}_{\mathrm{out}} \quad \text{and } \dot{Q} + \sum \dot{m}_{\mathrm{in}} h_{\mathrm{in}} = \dot{W} + \sum \dot{m}_{\mathrm{out}} h_{\mathrm{out}} \tag{2}$$

where $\dot{E}_{\mathrm{in}}$ is the rate of net energy transfer in and $\dot{E}_{\mathrm{out}}$ is the rate of net energy transfer out by heat, work and mass.

The rate of net heat input is given by

$$\dot{Q} = \dot{Q}_{\mathrm{net,in}} = \dot{Q}_{\mathrm{in}} - \dot{Q}_{\mathrm{out}} \tag{3}$$

The rate of net work output is calculated from

$$\dot{W} = \dot{W}_{\mathrm{net,out}} = \dot{W}_{\mathrm{out}} - \dot{W}_{\mathrm{in}} \tag{4}$$

Assuming that flows are one-dimensional, the input and output terms in Eq. (2) are net quantities after accounting for imports and exports and the accumulation term is zero, the following may be written

$$\sum_{\mathrm{in}} \dot{m}_{\mathrm{in}}(h + \mathrm{ke} + \mathrm{pe})_{in} - \sum_{\mathrm{out}} \dot{m}_{\mathrm{out}}(h + \mathrm{ke} + \mathrm{pe})_{out} + \sum_{\mathrm{r}} \dot{Q}_r - \dot{W} = 0 \tag{5}$$

where m_{in} and m_{ex} are the mass input across port '*in*' and existing across port 'ex', respectively. Q_r is the heat transfer into the system across *r* region on the system boundary, W is the work (including shaft work, electricity, etc.) transferred out of the system. h, ke and pe are the specific values of enthalpy, kinetic energy and potential energy, respectively.

The general exergy balance can be expressed in the rate form as, assuming that flows are one-dimensional, the input and output terms are net quantities after accounting for imports and exports and the accumulation term is zero, the following may be written

$$\sum_{\text{in}} m_{\text{in}}\text{ex}_{\text{in}} - \sum_{\text{out}} m_{\text{out}}\text{ex}_{\text{out}} + \sum_{\text{r}} \text{Ex}^{Q} - \text{Ex}^{W} - I = 0 \quad (6)$$

where ex denotes the specific exergy, Ex^Q and Ex^{W} are the exergy transfers associated with Q_r and W, respectively, and I is the system exergy consumption. The exergy consumption (I) is defined as (i) $I > 0$ for an irreversible process, and (ii) $I = 0$ for a reversible process [22].

The amount of thermal exergy transfer associated with heat transfer Q_r across a system boundary r at constant temperature T_r is

$$\text{Ex}^Q = [1 - (T_{\text{o}}/T_{\text{r}})]Q_{\text{r}} \quad (7)$$

The specific exergy of a mass flow with negligible potential and kinetic energy changes as well as no changes in the chemical composition can be written as

$$\text{ex}^{\text{PH}} = (h - h_0) - T_0(s - s_0) \quad (8)$$

where h and s are the specific enthalpy and entropy, and T is the temperature, while the subscript '0' denotes conditions of the reference environment.

The exergy of an incompressible substance may be written as follows

$$\text{Ex}_{\text{ic}} = C(T - T_0 - T_0 \ln T/T_0) \quad (9)$$

where C is the specific heat.

The amount of exergy consumed due to irreversibilities during a process is as follows

$$I = T_0 S_{\text{gen}} \quad (10)$$

where S_{gen} is the entropy generation.

3.1.1. Exergy of work

The exergy associated with work is

$$\text{Ex}^W = W \quad (11)$$

3.1.2. Chemical exergy

One of the most common mass flows is hydrocarbon fuels at near-ambient condition, and the specific exergy may be reduced to chemical exergy, which can be written as

$$\text{ex}_{\text{f}} = \gamma_{\text{f}} H_{\text{f}} \quad (12)$$

where γ_{f} denotes the fuel exergy grade function, defined as ratio of fuel chemical exergy to the fuel higher heating value H_{f}. Some typical values of H_{f}, γ_{f} and ex_{f} for the fuels encountered in the present study are listed in Table 1. Usually, the specific chemical exergy ε_{f} of a fuel at T_0 and P_0 is approximately equal to H_{f}. Natural gas has the highest chemical exergy value.

Table 1
Quality factors of energy carriers and flows used in the residential–commercial sector [2,17,36]

Energy carriers	Enthalpy (kJ/kg)	Chemical exergy (kJ/kg)	Quality factor
Natural gas	55,448	51,702	0.92
Hard coal	25,552	26,319	1.03
Fuel oil	47,405	47,101	0.99
LPG	45,460	45,005	0.99
Wood	12,252	12,865	1.03
Dried dung	9624	10,105	1.03
Geothermal	36,006.48	10,441.87	0.29
Electricity	3600.6	3600.6	1.00
Solar	36,006.48	33,485.58	0.93
Mechanical energy			1.00
Steam (600 °C)			0.60
District heating (90 °C)			0.2–0.3
Space heating (20 °C)			0–0.2
Earth			0

3.1.3. *Energy and exergy utilization efficiencies*

Energy (first-law) and exergy (second-law) utilization efficiencies in %, ε_1 and ε_2, can be defined as follows, respectively.

$$\varepsilon_1 = (\text{Energy in products/total energy input}) \times 100 \tag{13}$$

$$\varepsilon_2 = (\text{Exergy in products/Total exergy input}) \times 100 \tag{14}$$

3.1.4. *Heating*

Electric and fossil-fuel heating processes are taken to generate product heat Q_p at a constant temperature T_p either from electrical energy W_e or fuel mass m_f. The efficiencies for electrical heating and fuel heating are

$$\varepsilon_{1e,h} = Q_p/W_e \text{ and } \varepsilon_{1f,h} = Q_p/m_f H_f \tag{15}$$

$$\varepsilon_{2e,h} = \mathrm{Ex}^{Qp}/\mathrm{Ex}^{We} \quad \text{and} \quad \varepsilon_{2f,h} = \mathrm{Ex}^{Qp}/m_f \varepsilon_f \tag{16}$$

and hence

$$\varepsilon_{2e,h} = [(1-(T_0/T_p))Q_p]/(W_e) \text{ and } \varepsilon_{2f,h} = [(1-(T_0/T_p))Q_p]/(m_f \gamma_f H_f) \tag{17}$$

$$\varepsilon_{2e,h} = [(1-(T_0/T_p))]\varepsilon_{1e,h} \text{ and } \varepsilon_{2f,h} = [(1-(T_0/T_p))]\varepsilon_{1f,h} \tag{18}$$

where double subscripts indicate the processes in which the quantity represented by the first subscript is produced by the quantity represented by the second; e.g. the subscripts h, e, f, means heating electricity with fuel.

3.1.5. *Work production*

Electric and fossil fuel work production processes produces shaft work W. The efficiencies for shaft work production from electric and fossil fuels are as follows:

$$\varepsilon_{1e,w} = W/W_e \quad \text{and} \quad \varepsilon_{1f,w} = W/m_f H_f \tag{19}$$

$$\varepsilon_{2e,w} = Ex^{W}Ex^{We} = W/W_e = \varepsilon_{1e,w} \text{ and } \varepsilon_{2f,w} = Ex^{W}/m_f H_f = W/(m_f \gamma_f H_f) = \varepsilon_{1f,w}/\gamma_f \tag{20}$$

3.1.6. Kinetic energy production

The efficiencies for the fossil fuel-driven kinetic energy production processes, which occur in some devices in the transportation sector and which produces a change in kinetic energy Δke in a stream of matter m_s, are as follows:

$$\varepsilon_{1f,ke} = m_s \Delta ke_s / m_f H_f \tag{21}$$

$$\varepsilon_{2f,ke} = m_s \Delta ke_s / m_f \varepsilon_f = m_s \Delta ke_s / (m_f \gamma_f H_f) = \varepsilon_{1f,ke}/\gamma_{f,ke} \tag{22}$$

Different ways of formulating exergetic efficiency proposed in the literature have been given in detail elsewhere [48,49]. The exergy efficiency expresses all exergy input as used exergy, and all exergy output as utilized exergy. Therefore, the exergy efficiency ε_2 becomes

$$\varepsilon_2 = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} \tag{23}$$

Often, there is a part of the output exergy that is unused, i.e. an exergy wasted, $\dot{E}_{waste}$, to the environment. In this case, exergy efficiency may be written as follows [49]:

$$\varepsilon_2 = \frac{\dot{E}x_{out} - \dot{E}x_{waste}}{\dot{E}x_{in}} \tag{24}$$

Various ways of formulating exergetic efficiency (second-law efficiency, effectiveness, or rational efficiency) proposed in the literature have been given in detail elsewhere [50], while Hepbasli and Akdemir [51] gave its application to a ground-source (geothermal) heat pumps system and Ozgener et al. [10] studied on geothermal heating systems. Among these, Kotas [50] and Cornelissen [48] define the rational efficiency as the ratio of the desired exergy output to the exergy used, namely

$$\varepsilon_2 = \frac{Ex_{desired,output}}{Ex_{used}} \tag{25a}$$

where $Ex_{desired,output}$ is all exergy transfer from the system, which must be regarded as constituting the desired output, plus any by-product that is produced by the system, while Ex_{used} is the required exergy input for the process to be performed. The exergy efficiency given in Eq. (25a) may also expressed as follows [52];

$$\varepsilon_2 = \frac{\text{desired exergetic effect}}{\text{exergy used to drive the process}} = \frac{\text{`` product''}}{\text{`` fuel''}} \tag{25b}$$

To define the exergetic efficiency both a *product* and a *fuel* for the system being analyzed are identified. The product represents the desired result of the system (power, steam, some combination of power and steam, etc.). Accordingly, the definition of the product must be consistent with the purpose of purchasing and using the system. The fuel represents the resources expended to generate the product and is not necessarily restricted to being an actual fuel such as a natural gas, oil, or coal. Both the product and the fuel are expressed in terms of exergy [53].

Van Gool [54] has also noted that maximum improvement in the exergy efficiency for a process or system is obviously achieved when the exergy loss or irreversibility

($(\dot{E}x_{in} - \dot{E}x_{out})$) is minimized. Consequently, he suggested that it is useful to employ the concept of an exergetic 'improvement potential' when analyzing different processes or sectors of the economy. This improvement potential, denoted *IP*, is given by [21].

$$\mathrm{IP} = (1 - \varepsilon_2)(\dot{E}x_{in} - \dot{E}x_{out}) \tag{26}$$

3.2. Energy and exergy efficiency calculations in the residential– commercial sector

Residential–commercial sector includes space heating, water heating, cooking and electrical appliances. In all activities in this sector, based on electricity, heat is produced. Eq. (12) is a ratio of exergy-to-enthalpy amount of energy carrier, that is called quality factor (q) or exergy grade function, for some type of energy, which used in the RCS, such as mechanical, electrical energy, this value is equal to 1.

Table 1 represents quality factors for some energy carriers and forms which is used in the RCS [2,17,36]. Quality of heat is Carnot factor that strongly depends on temperature, as stated in the following equation.

$$Q_{carnot} = 1 - (T_0/T_p) \tag{27}$$

As input exergy, fossil fuel or electricity is used. If fossil fuel is used, then exergy is given by

$$\mathrm{Ex} = Q \times q \tag{28}$$

The obtained models for energy efficiency are linear equations, since they are only a function of temperatures. Besides this, exergy efficiency models are two or third-order polynomial correlations because they are affected by different parameters of process in the RCS. Polynomial equations are calculated by using MATLAB program. Energy and exergy efficiency values of these categories are determined separately as presented below.

3.2.1. Space heating

Heating options specified for heating systems are district heating, central heating, individual heating and stove. However, types of energy carriers used in space heating systems are coal, fuel oil, natural gas, wood, dried dung, geothermal and electricity. Energy and exergy efficiencies of each other energy carriers considered for all systems efficiencies were determined, while heating system and fuel preference of dwelling units were determined according to their utilization ratios.

Of all direct fuel 43–52% use was for space heating, which was done entirely by home heaters having the same first-law efficiencies of home stoves. In this study, dead state temperatures varied from 0 to 25 °C, while the temperature of the space heating is 50 °C. Quality factors of energy carriers are also taken from Table 1. According to these values, linear and two order polynomial correlations can be obtained for energy and exergy efficiencies of energy carriers, which are used for space heating. The energy efficiency correlations developed for various energy carriers are shown in Table 2, while the energy efficiency values plotted by taking into account these correlations are illustrated in Fig. 2.

The exergy efficiency of the space heating was calculated using

$$\varepsilon_2 = \left(\frac{\varepsilon_1}{q_{fuel}}\right)\left\{1 - \left[\frac{T_0}{T_2 - T_0}\right]\ln\left(\frac{T_2}{T_0}\right)\right\} \tag{29}$$

Table 2
Energy and exergy equations of energy carriers used in the residential–commercial sector

	Energy carriers	Exergy equation (%; T:°C)	R^2	Energy equation (%; T:°C)	R^2
Space heating	Coal stove	$-1.8T+90.00$	1	$0.0031T^2-0.2924T+7.1358$	1
	Coal district	$-1.4035T+84.2105$	1	$0.0024T^2-0.2695T+7.8470$	1
	Fuel-oil	$-2.0T+100$	0.99	$0.0035T^2+0.3380T+8.2491$	0.99
	Natural gas	$-0.0352T^2-0.2772T+99.1700$	1	$-0.0006T^2-0.2360T+10.3912$	1
	Wood	$-1.60T+80$	1	$0.0027T^2-0.2599T+6.3430$	1
	Dried dung	$-2.6316T+100$	1	$0.0044T^2-0.3746T+7.9279$	1
	Electricity	$-1.0T+100$	1	$0.0018T^2-0.3004T+13.5446$	1
	Geothermal	$-2.2222T+100$	1	$0.0170T^2-1.3973T+29.0186$	1
	LPG	$-0.0401T^2+0.1679T+97.8575$	1	$-0.0013T^2-0.1805T+9.5487$	1
Water heating	Natural gas	$-1.6667T+100$	1	$0.0032T^2-0.3583T+10.4324$	1
	Wood	$2.7778T+100$	1	$0.0046T^2-0.4229T+9.3169$	1
	LPG	$-0.0015T^2-1.5068T+100.7092$	0.99	$0.0027T^2-0.3207T+9.6950$	1
	Electricity	$-0.0246T^2-0.0140T+97.6012$	0.94	$-0.0018T^2-0.3004T+13.5446$	0.99
	Fuel-oil	$-1.6667T+100$	1	$0.0029T^2-0.3330T+9.6948$	0.99
	Dried dung	$-2.8571T+100$	1	$0.0047T^2-0.3848T+7.7766$	0.98
	Geothermal	$-2.5T+100$	1	$0.0151T^2-1.1715T+23.0135$	1
	Solar	$-1.6667T+100$	1	$0.0031T^2-0.3541T+10.3976$	0.99
Cooking	LPG	$0.0023T^2-0.5139T+51.4203$	1	$0.0018T^2-0.2884T+15.8494$	1
	Natural gas	$0.0023T^2-0.5139T+51.4203$	1	$0.0028T^2-0.3365T+17.2219$	0.99
	Wood	$-0.2470T+29.6339$	1	$0.0007T^2-0.1483T+7.9588$	0.99
	Electricity	$-0.0042T^2-0.9484T+94.9347$	1	$0.0033T^2-0.5272T+28.9694$	1
	Dried dung	$-0.2602T+26.0183$	1	$0.0008T^2-0.1418T+6.9878$	0.99

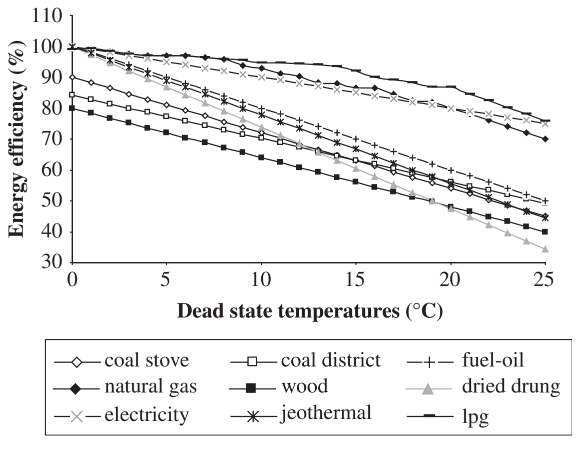

Fig. 2. Energy efficiencies of energy carriers used for space heating at varying dead state temperatures from 0 to 25 °C.

Fig. 3 illustrates exergy efficiency variation for varying dead state temperatures. The obtained exergy efficiency correlation results using Eq. (29) according to each of other energy carriers are given in Table 2.

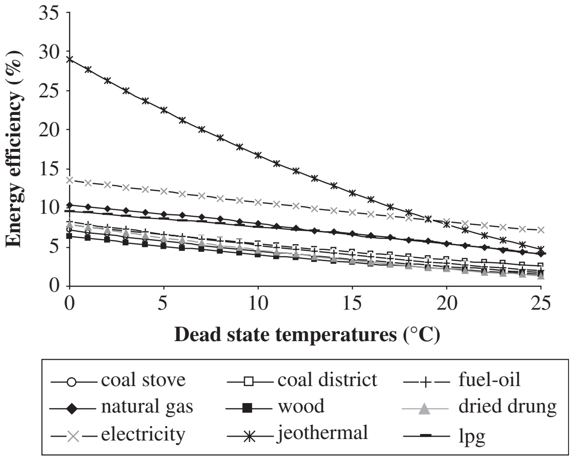

Fig. 3. Exergy efficiencies of energy carriers used for space heating at varying dead state temperatures from 0 to 25 °C.

By using actual system data and various dead state values ranging from 0 to 25 °C, two models are developed for energy carriers, which are used in the space heating. These models developed for estimating energy and exergy efficiencies of the space heating are a function of the temperature with coefficients of determination of R^2, which are listed in Table 2 for each of energy carriers. The above models are able to predict the values for energy and exergy efficiencies of the space heating according to their energy carriers.

Overall energy ($\varepsilon_{1\mathrm{osh}}$) and exergy ($\varepsilon_{2\mathrm{osh}}$) efficiencies of the space heating were calculated as follows:

$$\varepsilon_{1\mathrm{osh}} = [(a_1 \times \varepsilon_{1,1\mathrm{c}}) + (a_2 \times \varepsilon_{1,2\mathrm{c}}) + (a_3 \times \varepsilon_{1,3\mathrm{c}}) + \cdots + (a_9 \times \varepsilon_{1,9\mathrm{c}})]/100 \tag{30a}$$

$$\varepsilon_{2\mathrm{osh}} = [(a1 \times \varepsilon_{2,1\mathrm{c}}) + (a_2 \times \varepsilon_{2,2\mathrm{c}}) + (a_3 \times \varepsilon_{2,3\mathrm{c}}) + \cdots + (a_9 \times \varepsilon_{2,9\mathrm{c}})]/100 \tag{30b}$$

3.2.2. Water heating

Various energy carriers, such as natural gas, liquefied petroleum gas (LPG), wood, dried dung, solar and electricity are used in the water heating activities. Energy efficiencies of the energy carriers in the water heating are determined by producers using temperatures 25 and 60 °C. For instance, energy efficiency of electric water resistant is 98% and home gas water heater is 60% [55]. Energy efficiencies of the direct fuel use for the water heating are assumed to be 27–80% [40].

Here, energy efficiencies for energy carriers are determined according to the dead state temperature various ranging from 25 to 0 °C. These results can lead us to linear or two order polynomial equations for the energy efficiency of the energy carriers in the water heating. The obtained equations of the energy efficiency variation are indicated in Fig. 4. Thus, the calculated equations of the energy efficiency for the energy carriers in order to heat water are given in Table 2.

The exergy efficiency of the water heating is calculated by using Eq. (29). In the calculation, it is assumed that the task of heating water is to bring water temperature to 60 °C. The dead state temperatures varied from 0 to 20 °C and the quality factors of the energy carriers were taken from Table 1. Using the actual system data and various dead

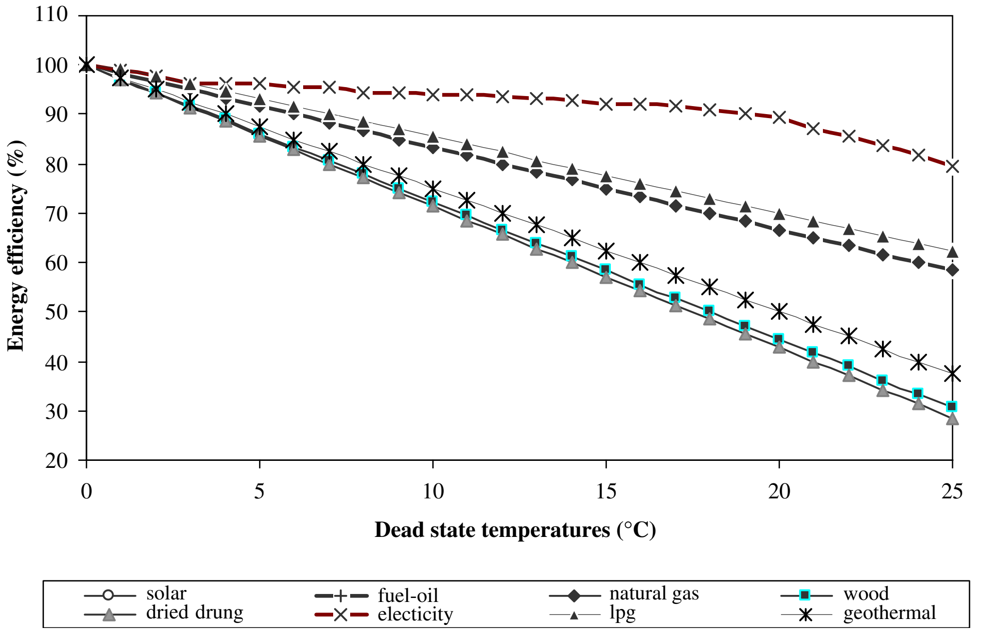

Fig. 4. Energy efficiencies of energy carriers used for water heating at varying dead state temperatures from 0 to 25 °C.

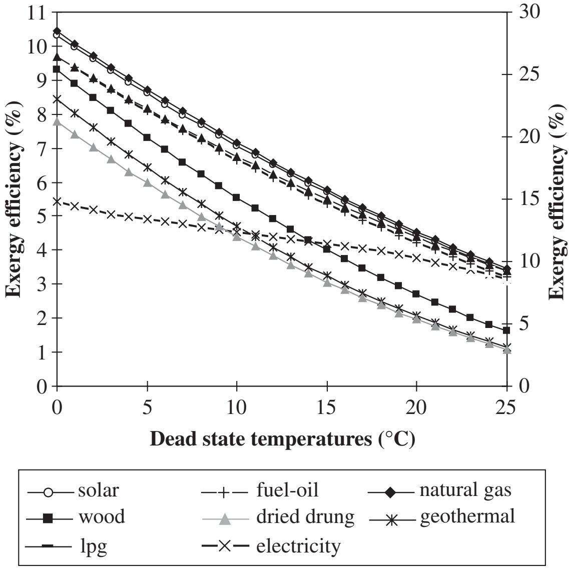

Fig. 5. Exergy efficiencies of energy carriers used for water heating at varying dead state temperatures from 0 to 25 °C. *Electric must be read from the right column. **Natural gas and LPG have the same efficiency.

state values stated above, the two order polynomial correlations developed are indicated with exergy efficiencies of the energy carriers in the water heating; as illustrated in Table 2, while the exergy efficiency variation of the water heating is shown in Fig. 5.

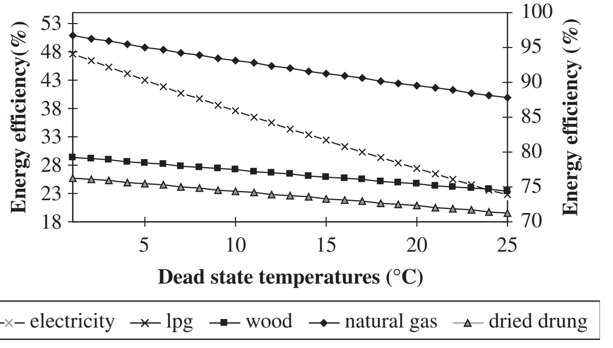

Fig. 6. Energy efficiencies of energy carriers used for cooking at varying dead state temperatures from 0 to 25 °C. *Electric must be read right column. **Natural gas and LPG have the same efficiency.

Overall energy (ε_{1owh}) and exergy (ε_{2owh}) efficiencies of the water heating were calculated from Eqs. (30a) and (30b) by considering the amount of the utilization of energy carriers.

3.2.3. *Cooking*

In cooking activities, various energy carriers are used that are natural gas, city gas, LPG, electricity, wood and dried dung. For cooking activities, energy efficiencies of energy carriers determined according to dead state temperatures varying from 0 to 25 °C. Process temperatures for cooking applications used in the calculations are 120 °C. Cooking efficiencies are assumed to be 50% for gas cooking stove, LPG, and natural gas, 80% for electric cooking stove, 22% for wood, and 20% for dried dung.

Linear and two order polynomial correlation models are developed for each of energy carriers, which are used in cooking and those equations are indicated in Table 2. In addition, Fig. 6 shows a variation of energy and exergy efficiencies versus dead state temperature for cooking process.

The exergy efficiencies of energy carriers for cooking activities were calculated by the following equation:

$$\varepsilon_2 = \varepsilon_1\left[1 - \left(\frac{T_0}{T_2}\right)\right] \tag{31}$$

The energy efficiency models are taken from Table 2 for cooking and quality factors of energy carriers are obtained from Table 1. Cooking temperature was taken to be 120 °C and the dead state temperatures varied from 0 to 25 °C. Thus, the polynomial models obtained are shown in Table 2, while a variation of exergy efficiencies for cooking activities is illustrated in Fig. 7.

Overall energy (ε_{1oc}) and exergy (ε_{2oc}) efficiencies were calculated from Eqs. (30a) and (30b) by considering the amount of utilization of energy carriers in cooking activities.

Overall sectoral energy and exergy efficiencies for the energy and exergy utilization were calculated by the following equations, respectively.

$$e_{1of} = [(f_{sh} \times \varepsilon_{1osh}) + (f_{wh} \times \varepsilon_{1owh}) + (f_c \times \varepsilon_{1oc})]/100 \tag{32a}$$

$$\varepsilon_{2of} = [(\mathrm{f}_{sh} \times \varepsilon_{2osh}) + (\mathrm{f}_{wh} \times \varepsilon_{2owh}) + (\mathrm{f}_c \times \varepsilon_{2oc})]/100 \tag{32b}$$

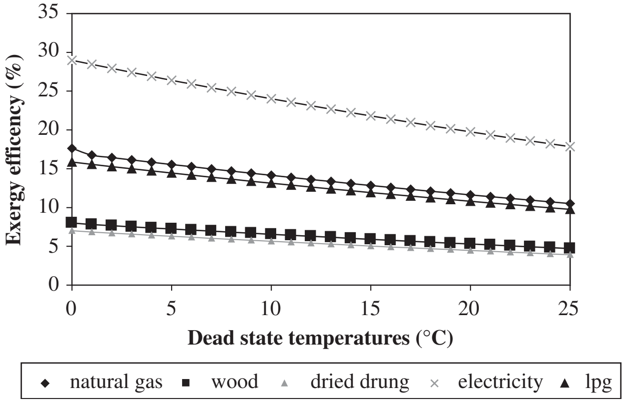

Fig. 7. Exergy efficiencies of energy carriers used for cooking at varying dead state temperatures from 0 to 25 °C.

Substituting the relevant numerical values into Eqs. (32a) and (32b), we obtained energy and exergy efficiencies for the energy and exergy utilization in the space heating, water heating and cooking activities in the RCS.

3.2.4. Electrical appliances

Electrical appliances include lighting, refrigerator, air-conditioning, dish washer, washing machine, iron, television, computer and others appliances, such as hair dryer, and mechanical drive. Space heating, cooking and water heating efficiencies of the electrical appliances were taken as stated in the following subsections.

In the residential–commercial sector, electricity is primarily consumed for refrigeration, lighting, air conditioning and other activities. The output is mechanical or electrical energy that its exergy content is equal to energy content.

3.2.4.1. Lighting. Approximately 35–38% of all electrical use was for lighting [56]. Lighting is assumed to be incandescent and fluorescent with energy and exergy efficiencies of about 5 and 4.5%, and 20 and 18.5% in the residential–commercial sector, respectively [36,43]. Utilization ratio of fluorescent and incandescent in lighting is determined as given in Table 6. Combining the relevant energy and exergy efficiencies for lighting, we calculated for the years considered, as indicated in Table 3 and these values are illustrated for other electrical appliances in Figs. 8 and 9.

3.2.4.2. Refrigeration and air-conditioning. For electrical appliances, input exergy is equal to input energy as explained above. However, in refrigeration and air conditioning applications, the purpose is to extract heat instead of producing heat. Exergy content of the extracted heat is then

$$\mathrm{Ex} = \mathrm{Q}_{\text{extracted heat}}[(T_0/T_p) - 1] \tag{33}$$

Refrigerators consume a significant share of electricity. 35–40% of all electrical use was for refrigeration [56,57]. Electricity consumption is projected to decrease by using new technologies for refrigerators. It is assumed that the temperatures inside freezers and

Table 3
Energy and exergy equations of electrical appliances used in the residential–commercial sector

Energy carriers	Energy equation (%, T, °C)	R^2	Exergy equation (%, T, °C)	R^2
Refrigeration	$0.0466T^2 - 2.0118T + 30.4948$	0.98	$0.0155T^2 - 0.1087T + 6,2757$	1
Air condition	$-0.0019T^2 + 0.4080T + 197.8795$	1	$0.012T^2 - 0.6867T + 3.4641$	1
Clothes dry	$-1.3333T + 100$	1	$0.0038T^2 - 0.5754T + 21.5424$	0.99
Dishes machine	$-2.000T + 100$	1	$-0.2941T + 14.7059$	1
Iron	$-0.6667T + 100$	1	$-0.2317\mathrm{T} + 34.7518$	1
Washing machines	70		70	
Vacuum cleaner	70		70	
Computer	75		75	
Television	75		75	
Lighting	9.80		8.7	
Others	64		64	

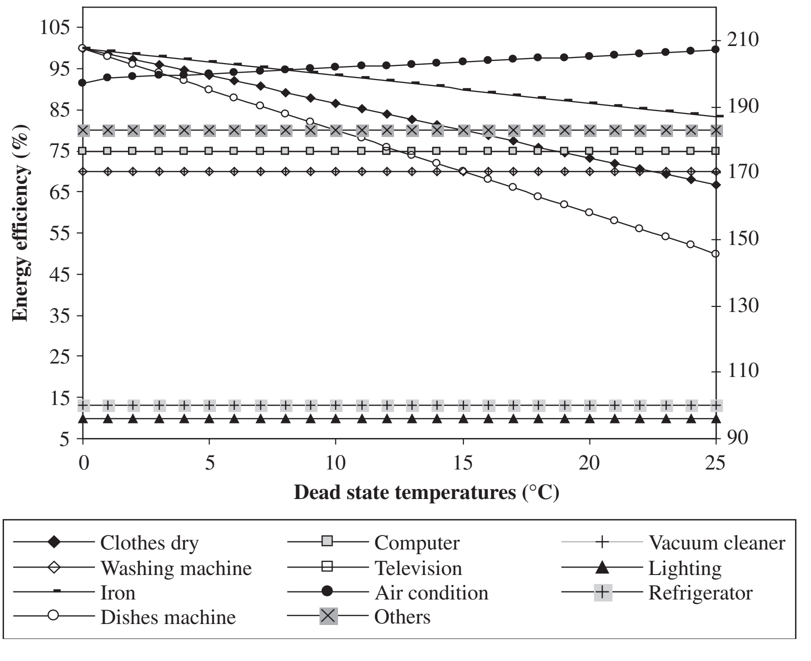

Fig. 8. Energy efficiencies of electrical appliances used in residential–commercial sector at varying dead state temperatures from 0 to 25 °C. *Refrigerator and air-conditioning must be read from the right column.

refrigerators are approximately −8 °C, while the room temperature near the refrigerator coil is 20 °C. The two-third order polynomial correlations obtained for refrigeration and air-conditioning devices are given in Table 3, while the achieved energy efficiency values from these correlations are illustrated in Fig. 8. The models developed are able to predict values of exergy efficiency for these applications.

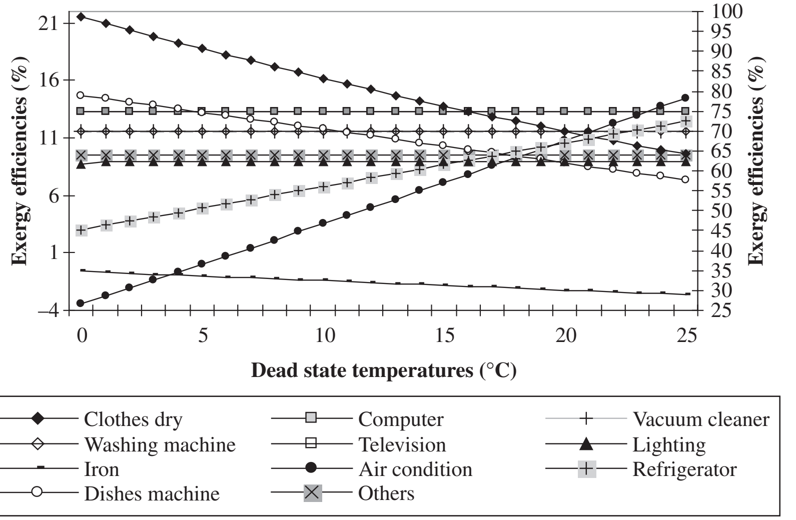

Fig. 9. Exergy efficiencies of electrical appliances used in residential–commercial sector at varying dead state temperatures from 0 to 25 °C. *Iron, computer, television, vacuum cleaners and other must be read from the right column.

The exergy efficiency of refrigeration was calculated from

$$\varepsilon_2 = \varepsilon_1\left[\left(\frac{T_0}{T_3}\right) - 1\right] \tag{34}$$

It is assumed that the temperatures for air-conditioning are 33 and 13 °C, the coefficient of performance (COP) is 2.0, as suggested by Ford [58]. Using Eq. (34), these assumptions yield the two-third order polynomial correlations given in Table 3 for refrigeration and air-conditioning devices. The exergy efficiency values obtained from these correlations are illustrated in Fig. 9.

3.2.4.3. Dish washes and iron. Process temperatures are assumed to be 50 °C for dishwasher and 150 °C for iron. The linear and two-order polynomial correlations developed for dishes washes and iron are given in Table 3, while their energy efficiency values are illustrated in Fig. 8.

Dish washer and iron are heat-producing appliances evaluated using

$$\varepsilon_2 = Q_{\text{output}} \times [1 - (T_{\text{o}}/T_{\text{p}})]/q \times W_{\text{elect,input}} \tag{35}$$

$$\varepsilon_2 = \varepsilon_1 \times (1 - T_{\text{o}}/T) \tag{36}$$

Using Eqs. (35) and (36), these assumptions yield the two-order polynomial correlations developed for dishes washes and iron given in Table 3, while the exergy efficiency values obtained from these correlations are illustrated in Fig. 9.

3.2.4.4. Television and computer. Of all electrical use 6–7% was for television and computer. Annual electricity consumption of television has increased compared to

previous years as a result of an increase in the number of TV channels, a longer daily broadcast period and utilization of colored TVs. Energy and exergy efficiencies are assumed to be 75% [43], as shown in Table 3 and Figs. 8 and 9.

3.2.4.5. Washing machine and vacuum cleaner. If electrical or mechanical energy is output, the following equation is valid since the quality factor of both energy forms are equal to 1.

$$\varepsilon_2 = q_{\mathrm{elec}} \times W_{\mathrm{elec(or\ mech)}}/q_{\mathrm{elec}} \times W_{\mathrm{elec}} = \varepsilon_1 \tag{37}$$

Mechanical drive requirements in the RCS are met by small electric motors and both energy and exergy efficiencies are about 70%. Washing machine, vacuum cleaner, television and others are assumed as electricity or mechanical work producers and are evaluated according to Eq. (37). Energy and exergy efficiency values are assumed to be 70% [43], as illustrated in Figs. 8 and 9.

3.2.4.6. Others. Electricity consumption values of other electrical appliances, for instance, hair drying were selected, as given in Table 4, while the energy and exergy efficiencies of these appliances are listed in Fig. 9 and shown in Figs. 8 and 9.

Substituting the relevant numerical values into Eqs. (30a)–(30b), we found energy and exergy efficiencies for electrical use in the analyzed year.

Overall energy and exergy efficiencies for the entire RCS are determined by following the procedure given below.

(i) Energy carriers that include fuel, renewable and electricity are taken into account.
(ii) Values of energy and exergy utilization in the RCS are estimated according to energy carriers and subsectors. Total energy consumption in this sector may be obtained from energy statistics and reports.
(iii) Space and water heating, cooking system preferences of buildings and commercials using energy carriers for these purposes are determined. These preferences can be obtained from annual statistics.
(iv) Saturation of electrical appliance values is determined in this sector. In addition, total annual electricity consumption determined for electrical activities is achieved from energy reports.
(v) Energy and exergy efficiencies are calculated one by one for the utilization of fuel including fossil and renewable and electricity.
(vi) In this sector, overall energy and exergy efficiencies ($\varepsilon_{1,\mathrm{orc}}$ and $\varepsilon_{2,\mathrm{orc}}$) for the entire RCS are calculated by aggregating both purchased electrical energy and direct fuel use as follows:

$$\varepsilon_{1,\mathrm{orc}} = \frac{(\varepsilon_{1\mathrm{e}} \times e_{\mathrm{rc}} + \varepsilon_{1\mathrm{of}} \times f_{\mathrm{erc}})}{(e_{\mathrm{rc}} + f_{\mathrm{erc}})} \tag{38a}$$

$$\varepsilon_{2,\mathrm{orc}} = \frac{(\varepsilon_{2\mathrm{e}} \times e_{\mathrm{rc}} + \varepsilon_{2\mathrm{of}} \times f_{\mathrm{exrc}})}{(e_{\mathrm{rc}} + f_{\mathrm{exrc}})} \tag{38b}$$

Using the numerical values obtained from the previous models, the weighted mean overall energy and exergy efficiencies for the entire RCS were found.

Table 4
Energy and exergy inputs to the Turkish residential–commercial sector during 2003

Energy carrier	Toe/q[a]		Total input (PJ)	Total input (%)	Residential–commercial inputs to Sector (PJ)	Sector (%)	Turkey (%)
Hard coal	0.61	Energy	452.97	12.96	25.09	3.10	5.54
	1.03	Exergy	466.56	13.57	25.84	3.28	5.54
Lignite	0.21	Energy	404.82	11.58	52.20	6.45	12.90
	1.04	Exergy	421.01	12.24	54.29	6.89	12.90
Asphaltite	1.03	Energy	0.09	0.003	N/A	N/A	N/A
	0.97	Exergy	0.09	0.003	N/A	N/A	N/A
Petroleum	1.05	Energy	1346.06	38.50	109.51	13.53	8.14
	0.99	Exergy	1332.60	38.75	108.41	13.76	8.14
Natural gas	0.91	Energy	813.02	23.25	147.32	18.20	18.12
	0.92	Exergy	747.98	21.75	135.54	17.21	18.12
Wood	0.30	Energy	187.99	5.38	187.99	23.23	100
	1.05	Exergy	197.39	5.74	197.39	25.06	100
Biomass	0.23	Energy	52.29	1.50	52.29	6.46	100
	1.05	Exergy	54.91	1.60	54.91	6.97	100
Hydropower	0.09	Energy	127.00	3.63	187.89	23.21	147.94
Geothermal (Electric)							
	1.00	Exergy	127.00	3.69	187.89	23.85	147.94
	0.86	Energy	3.20	0.09	N/A	N/A	N/A
	1.00	Exergy	3.20	0.09	N/A	N/A	N/A
Geothermal (Heat)	1.00	Energy	32.77	0.94	32.77	4.05	100
	0.29	Exergy	9.50	0.28	9.50	1.21	100
Solar	1.00	Energy	14.63	0.42	9.66	1.19	66
	0.93	Exergy	13.61	0.40	8.98	1.14	66
Wind	0.09	Energy	0.22	0.01	N/A	N/A	N/A
	1.00	Exergy	0.22	0.01	N/A	N/A	N/A
Coke	0.7	Energy	15.92	0.46	4.65	0.57	29.23
	1.05	Exergy	16.71	0.49	4.88	0.62	29.23
Petrocoke	0.77	Energy	45.16	1.29	0.05	0.01	0.12
	1.04	Exergy	47.87	1.39	0.06	0.01	0.12
Total		Energy	3496.15	100	809.42	100	23.15
		Exergy	3438.66	100	787.68	100	22.91

[a]The upper values are conversion factor to tons oil of equivalent (toe), while the lower values are quality factor.

4. An illustrative example

Earlier studies conducted on the energy and exergy analyses of Turkey are based on the values of the stable dead state temperatures of process. As for studies performed on Turkey's sectoral (commercial, residential, industrial and transportation) energy and exergy analyses, to date, thirteen studies [12,33–44] were realized. The present study analyzes the energy and exergy uses of the TRCS-based on varying dead state temperatures of process. In the calculations, the actual data for 2003 were used.

Total energy and exergy inputs for the same period according to energy carriers are illustrated in Table 4. By 2003, Turkey's population and dwelling unit are determined to be 70,778,000 and 16,237,852, respectively [59]. As can be seen in this table, the total energy

and exergy inputs to the Turkish sector were 3496.15 and 3438.66 PJ in 2003, respectively. In addition, per/capita for total energy consumption and for the RCS were determined to be 49.40 and 11.44 GJ/capita in studied year, respectively.

Of total energy input, 28.34% was produced in 2003, while the rest was met by imports. In 2003, the production of 11 energy sources was the biggest share of the total coal including lignite and hard coal with 45.37%, followed by wood with 18.89%, hydropower with 12.75%, and petroleum with 10.47%. In 2003, renewable energy source production was the second biggest production source after total coal production, providing about 42% of the energy production.

In 2003, of Turkey's total end-use energy, 42% was used by the industrial sector, followed by the RCS at 31%, the transportation sector at 19%, the agricultural sector at 4.8%, and the non energy (out of energy) use at 3.2% [46,59].

4.1. Analyzing the energy and exergy utilization in the Turkish residential–commercial sector

The TRCS includes space heating, water heating, cooking and electrical appliances for energy consumption. In the following subsections, the utilization of energy and exergy in the TRCS in 2003 is analyzed. The figures for energy and exergy consumptions were determined for 2003, as shown in Table 4. In 2003, of Turkey's end use energy, 31% was used by the residential sector, while the share of this sector in this breakdown is expected to continue to decrease at approximately 9–12% per year and to reach 20% in 2020. Table 5 illustrates the use of energy and exergy as well as the shares of the resources in this sector for 2003.

Energy and exergy utilization values for the year studied in the TRCS are shown in Table 4. The highest contributions came from fuel with 41.87%, renewable resources (includes wood) with 34.91% and electric with 23.22% in 2003. In 2003, the highest

Table 5
Distribution of residences and efficiencies according to fuel types and components of fuel uses in 2003 (%)

	Space heating (ratio of residence)			Stove	Water heating (ratio of residence)	Cooking (ratio of residence)
	District heating	Central heating	Individual heating			
Energy carriers						
Coal (stove)				71.4		
Coal	57	37				
Fuel-oil	21	24	5	0.8	2.04	
Natural gas	19	39	95	4.10	2.16	10.5
LPG				1.00	4.18	89.1
Electricity				3.6	7.8	0.3
Wood				1.9	31.65	0.1
Geothermal	3				0.3	
Solar					14.15	
Dried dung				0.1	0.10	
Total	100	100	100	100	100	100
Ratio of residences	4.2	6.25	6.1	83.45	100	100

contributions came from wood with 187.99 PJ, while the share of this resource in this breakdown is expected to continue to decrease at approximately 3–5% per year and to reach 128.54 PJ in 2020 [43]. However, natural gas utilization has continuously increased in the TRCS for space heating, water heating and cooking purposes in several cities. According to 2000 year [40], utilization of this energy carrier raised about 40%, and reached 147.32 PJ of used energy in this sector in 2003. In addition, utilization of renewable energy was spread in the TRCS, especially from sunlight for water heating, from geothermal for water heating and space heating and from bio-waste for general utilization.

Share of the energy utilization in the residential–commercial modes is as follows: Space heating with 43%, water heating with 27%, cooking with 10% and electrical appliances with 23% in the year studied, respectively. These values are determined for 2003 using the data obtained from World Energy Council-Turkish National Committee [59].

4.2. Estimation of the component and overall efficiencies for space heating

Various fuels given in Table 1 are used for the purposes of water heating, space heating and cooking activities in this sector. Energy utilization values for the TRCS are also indicated in Table 5. Space heating requires the largest fraction of fuel with about 43%, while water heating and cooking are responsible for 36 and 21% of the total fuel inputs in this year, respectively.

Based on the values obtained from Turkey's population census, the fuel preferences of dwelling units for space heating were determined for each province, while energy consumptions in residences were predicted according to Turkey's geographical regions and selected provinces in 1998 [57]. The distribution of heating systems according to their utilization ratios for 1998 is as follows: District heating at 2.50%, central heating at 5.30%, individual heating at 4.30%, stove at 84.10% and others 3.80%.

The fuel consumption estimation methods in the literature are based on complete heating of space, whereas in stove heating, space is partially heated. Central heating methods can be adapted to other countries; stove heating must be analyzed based on national data. In a study performed by Aycik et al. [60], thermal efficiencies of coal- and wood-fired stoves used in Turkey were found to be on average 45 and 35%, respectively. Besides this, according to the Turkish Standard (TS) 4900, the thermal efficiencies of coal-fired stoves should be greater than 70% [61]. It is assumed that average efficiencies of stoves in the country will increase 2% in every five years up to 2020.

The contribution of geothermal energy to the TRCS was 55.25 PJ for space heating in 2003. However, it is expected that geothermal utilization will continue to increase to 190.50 PJ in 2020 in direct use of geothermal energy for heating [43].

Of all direct electrical use 2–3% was for space heating. It is assumed that energy efficiency is 98%, the supply temperature for the space heating equipment is 50 °C and the ambient temperature is 20 °C [12,35]. Using Eq. (18), the numerical values and the energy efficiencies assumed, we found $\varepsilon_2 = 7.3\%$ for space heating.

The energy and exergy efficiency values of space heating were calculated as follows: 43% of all direct fuel use was for space heating. This is done entirely by home heaters having the same first-law efficiencies of home stoves. Quality factor of energy carriers are taken from Table 1. The needed temperature for the space heating equipment is 50 °C and the ambient temperature varies from 0 to 25 °C. Polynomial and linear equations

used here are taken from Table 2. Heating system and fuel preferences considered are given in Table 5 for 2003. Overall energy ($\varepsilon_{1sh,f}$) and exergy ($\varepsilon_{2sh,f}$) efficiencies of space heating were calculated as follows: Substituting the relevant numerical values into Eqs. (30a) and (30b), we obtained $\varepsilon_{1sh} = 48.83 - 89.99\%$ $\varepsilon_{2sh} = 2.24 - 7.74\%$ in 2003 for space heating at dead state temperatures of 25 and 0 °C, respectively, as shown in Tables 7 and 8.

4.3. Estimation of the component and overall efficiencies for water heating

Based on the values obtained from Turkey's population census, the fuel preferences of dwelling units for wafer heating were determined for each province in 2003. 36% of all energy carrier use was for water heating. In 2003, 32% of all renewable energy use was for water heating. Ratio of residences with solar collectors for water heating in 2003 was at 14.15%. Although Turkey has a huge, solar energy potential, of this potential is used only small part for water heating. Of all electrical use 4% was for water heating in that year. Other preferences are listed in Table 5.

The energy and exergy efficiencies of space heating were determined as follows: Quality factor of energy carriers is given in Table 1. The supply temperature for the water heating equipment is 60 °C. The polynomial equations used are taken from Table 2. Fuel preferences considered are given in Table 5 for 2003. Overall energy ($\varepsilon_{1sh,f}$) and exergy ($\varepsilon_{2sh,f}$) efficiencies of water heating were calculated using Eqs. (30a) and (30b) and the numerical values assumed. So, we found $\varepsilon_{1wh,f} = 52.43$ and 100.00%, and $\varepsilon_{2wh,f} = 2.245$ and 7.74% in 2003 at dead state temperatures of 25 and 0 °C for water heating, respectively, as indicated in Tables 7 and 8.

4.4. Estimation of the component and overall efficiencies for cooking

In cooking activities, various fuels such as natural gas, city gas, LPG, etc. are used. Of all direct fuel use 21% was for cooking. The energy and exergy efficiencies of cooking are calculated in a similar manner as given in water and space heating. The cooking temperature is assumed to be 120 °C. Overall energy (ε_{1c}), and exergy (ε_{2c}), efficiencies are calculated from Eqs. (30a) and (30b) in a similar way and are found to vary from 40.10 to 51.56% and 11.68 to 19.03% at varying dead state temperatures from 25 to 0 °C for cooking in 2003, respectively. These values are presented in Tables 7 and 8.

4.5. Estimation of the overall efficiency and effectiveness values for electric utilization

As living standards rise, use of electrical appliances is increasing fast and boosting electricity demand. Increasing use of air-conditioning devices, especially in the Mediterranean region, has shifted the peak hours of electricity demand to noon in the summer. Electrical energy is used for various purposes such as lighting, refrigeration, television, washing machine, etc. in this sector. Energy utilization values for the TRCS as well as the saturation values of electrical appliances are given in Table 6. Refrigeration requires the largest fraction of electricity with 40% in the year studied, followed by lighting with 35%. The polynomial equations used are given in Table 3. The overall efficiency and effectiveness values for electric utilization are estimated as follows.

Table 6
Values for energy and exergy utilization efficiencies as well as utilization of electric and saturation values of electrical appliances in 2003

Component	Ratio of saturation 1998[a] (%)	Ratio of saturation 2003[a] (%)	Utilization of electric (%)
Lighting	100	100	35
Incandescent	80	68	68
Fluorescent	20	32	32
Refrigeration	97.38	99	40
Water heating	3.6	5.9	2
Cooking	74.57	90	3
Space heating	1.5	2	1
Washing machine	78.97	89.1	3
Dishes machine	14.49	33.5	1
Vacuum cleaner	77.21	90.4	2
Air-conditioning	1.26	3.25	3
Television	96.59	99	4
Iron	92.54	97.25	1
Hair drying machine	61.62	83.5	1
Computer	0.95	4.56	4
Overall electrical utilization	100		

[a]The values for 1998 are obtained from Ref. [57], while those are achieved using Ref. [59].

4.5.1. *Lighting*

Approximately 35% of all electrical use was for lighting [56,57]. Electrical energy consumption value for lighting was 138 kWh per dwelling unit annually in 1990 [56]. Annual electricity consumption of dwelling unit for lighting is assumed to change linearly from 138 kWh, reaching 180 kWh in 2003, 230 kWh in 2010 and 260 kWh in 2020 [36,43]. Lighting is assumed to be 68% incandescent and 32% fluorescent with energy and exergy efficiencies of about 5 and 4.5%, and 20 and 18.5%, in 2003, respectively [56,43]. Combining the relevant energy and exergy efficiencies for lighting, we calculated $\varepsilon_{1,1} = 9.5-15.5\%$ and $\varepsilon_{2,1} = 8.70-14.3\%$ at varying dead state temperatures from 25 to 0 °C.

4.5.2. *Refrigeration and air-conditioning*

Refrigerators are consumed huge share of electricity. 40% of all electrical use was for refrigeration [56,57]. Electricity consumption is projected to decrease by using new technologies for refrigerators. Average annual consumption was calculated to be 346 kWh in 1990, 328 kWh in 1995 and 300 kWh in 2001 and 2005, and 275 kWh in 2020 [36]. The energy and exergy efficiencies of refrigeration are calculated by using polynomial equations given in Table 3. It is assumed that the temperatures inside freezers and refrigerators are approximately −8 °C, the coefficient of performance (COP) is 1.0. Using Eq. (31), these assumptions yield exergy efficiencies ranging from 3.44 to 12.44% in 2003. Assuming that the COP value of the electric air-conditioning unit is two, this unit extracts heat from air at 14 °C and the outside temperature is from 33 °C and using Eq. (31) in a similar manner, we found $\varepsilon_{2,a} = 14.46\%$ at 25 °C in the year studied.

4.5.3. Television and computer

Of all electrical use 6–7% was for television and computer. Annual electricity consumption of television and computer has increased compared to the previous years as a result of an increase in the number of TV channels, a longer daily broadcast period and utilization of colored TVs and usage of computer spread in daily life as at school and work in Turkey. Energy and exergy efficiencies are assumed to be 75%.

4.5.4. Dish washes and iron

Dish washer, iron, are heat-producing appliances that they are evaluated according to the polynomial equation given in Table 3. Process temperatures for dishwasher and iron are assumed to be 50 and 150 °C, respectively. Using the polynomial and linear equations and the numerical values assumed, we found energy and exergy efficiencies $\varepsilon_{1\mathrm{whr}} = 50$ and 83%, and $\varepsilon_{2\mathrm{whfr}} = 7.35$ and 28.95% for 25 °C, and $\varepsilon_{1\mathrm{whr}} = 100$ and 100%, and $\varepsilon_{2\mathrm{whfr}} =$ 14.70 and 34.75% for 0 °C in the year studied for dishes washing and iron, respectively.

4.5.5. Washing machine and vacuum cleaner

Mechanical drive requirements in the RCS are met by small electric motors. Both energy and exergy efficiencies are taken to be 70%.

4.5.6. Others

Electricity consumption values of other electrical appliances, for instance hair drying, were estimated as given in Table 4, while the total energy and exergy efficiencies of these appliances are listed in Tables 7 and 8. Substituting the relevant numerical values into Eqs. (30a) and (30b), we found energy efficiencies from 64.19 to 65.09% and exergy efficiencies from 14.95 and 19.27% for electrical use at varying dead state temperatures from 25 to 0 °C. These values are also indicated in Tables 7 and 8, while a variation of efficiencies are illustrated in Figs. 10 and 11 for 2003 in the TRCS.

4.6. Energy and exergy utilization efficiencies in the whole Turkish residential–commercial sector

Overall energy and exergy efficiencies ($\varepsilon_{1,\mathrm{orc}}$ and $\varepsilon_{2,\mathrm{orc}}$) for the entire RCS were calculated from Eqs. (38a) and (38b) by aggregating both purchased electrical energy and direct fuel use. Using the numerical values given in Table 7, the weighted mean overall energy efficiencies for the entire RCS were found to vary from 51.95 to 80.82% in 2003 at varying dead state temperatures from 25 to 0 °C. Overall exergy efficiencies in the year studied for the entire RCS were found to range from 8.11 to 11.92% in 2003 at varying dead state temperatures from 25 to 0 °C. Numerical values are given in Table 8. This sector shows considerably important and comparable losses of energy and exergy. In terms of exergy loses, this sector ranks very differently, accounting for about 88–92% of all exergy loses.

This study indicated that exergy utilization in Turkey was even worse than energy utilization. In other words, Turkey represents a big potential for increasing the exergy efficiency. It is clear that a conscious and planned effort is needed to improve exergy utilization in Turkey. Considering the existence of energy-efficient technologies in the world, the major problem is delivering these technologies to consumers or, in other words, using effective energy-efficiency delivery mechanisms, as reported in detail elsewhere

Table 7
Energy efficiencies values of the Turkish residential–commercial sector in 2003 at varying dead state temperatures

Dead state temperatures (°C)	Space heating ε_1 (%)	Ratio (%)	Water heating ε_1 (%)	Ratio (%)	Cooking ε_1 (%)	Ratio (%)	Overall fuel efficiencies ε_1 (%)	Ratio (%)	Electrical appliances ε_1 (%)	Ratio (%)	Total sector efficiencies ε_1 (%)
25	48.83	43	52.43	36	40.10	21	48.29	77	64.19	23	51.95
24	50.59	43	54.44	36	40.51	21	49.86	77	64.23	23	53.16
23	52.35	43	56.46	36	40.92	21	51.43	77	64.26	23	54.38
22	54.11	43	58.42	36	41.33	21	52.98	77	64.30	23	55.58
21	55.87	43	60.39	36	41.75	21	54.53	77	64.33	23	56.79
20	57.64	43	62.40	36	42.17	21	56.10	77	64.37	23	58.00
19	59.38	43	64.31	36	42.60	21	57.63	77	64.41	23	59.19
18	60.96	43	66.21	36	43.03	21	59.08	77	64.44	23	60.32
17	62.71	43	68.10	36	43.46	21	60.61	77	64.48	23	61.50
16	64.46	43	69.96	36	43.90	21	62.12	77	64.51	23	62.67
15	65.97	43	71.82	36	44.35	21	63.53	77	64.55	23	63.77
14	67.66	43	73.70	36	44.79	21	65.03	77	64.58	23	64.93
13	69.20	43	75.57	36	45.25	21	66.46	77	64.62	23	66.04
12	70.93	43	77.44	36	45.70	21	67.98	77	64.66	23	67.21
11	72.53	43	79.30	36	46.16	21	69.43	77	64.69	23	68.34
10	74.25	43	81.16	36	46.63	21	70.94	77	64.73	23	69.51
9	75.88	43	83.01	36	47.10	21	72.40	77	64.76	23	70.65
8	77.61	43	84.86	36	47.58	21	73.91	77	64.80	23	71.82
7	79.18	43	86.77	36	48.06	21	75.38	77	64.84	23	72.95
6	80.74	43	88.62	36	48.54	21	76.81	77	64.87	23	74.07
5	82.25	43	90.52	36	49.03	21	78.25	77	64.91	23	75.18
4	83.73	43	92.37	36	49.53	21	79.66	77	64.94	23	76.27
3	85.33	43	94.21	36	50.03	21	81.11	77	64.98	23	77.40
2	86.92	43	96.15	36	50.53	21	82.60	77	65.01	23	78.56
1	88.53	43	98.07	36	51.04	21	84.09	77	65.05	23	79.71
0	89.99	43	100.00	36	51.56	21	85.53	77	65.09	23	80.82

Table 8
Exergy efficiencies values of the Turkish residential–commercial sector in 2003 at varying dead state temperatures variations

Dead state temperatures (°C)	Space heating ε_2 (%)	Ratio (%)	Water heating	Ratio (%)	Cooking ε_2 (%)	Ratio (%)	Overall fuel efficiencies ε_2 (%)	Ratio (%)	Electrical appliances ε_2 (%)	Ratio (%)	Total sector efficiencies ε_2 (%)
25	2.24	43	3.23	36	11.68	21	4.58	76	19.27	24	8.11
24	2.40	43	3.43	36	11.93	21	4.77	76	19.10	24	8.21
23	2.57	43	3.65	36	12.17	21	4.97	76	18.92	24	8.32
22	2.74	43	3.87	36	12.42	21	5.18	76	18.75	24	8.43
21	2.91	43	4.09	36	12.68	21	5.39	76	18.57	24	8.55
20	3.10	43	4.33	36	12.93	21	5.60	76	18.40	24	8.67
19	3.28	43	4.56	36	13.19	21	5.82	76	18.23	24	8.80
18	3.46	43	4.79	36	13.46	21	6.04	76	18.05	24	8.92
17	3.66	43	5.03	36	13.73	21	6.27	76	17.88	24	9.06
16	3.87	43	5.28	36	14.00	21	6.50	76	17.70	24	9.19
15	4.06	43	5.53	36	14.28	21	6.73	76	17.53	24	9.33
14	4.27	43	5.79	36	14.56	21	6.98	76	17.36	24	9.47
13	4.48	43	6.05	36	14.85	21	7.22	76	17.19	24	9.61
12	4.71	43	6.32	36	15.14	21	7.48	76	17.01	24	9.77
11	4.93	43	6.60	36	15.43	21	7.74	76	16.84	24	9.92
10	5.17	43	6.88	36	15.73	21	8.00	76	16.67	24	10.08
9	5.40	43	7.17	36	16.03	21	8.27	76	16.50	24	10.25
8	5.66	43	7.46	36	16.34	21	8.55	76	16.32	24	10.42
7	5.90	43	7.77	36	16.66	21	8.83	76	16.15	24	10.59
6	6.15	43	8.08	36	16.97	21	9.12	76	15.98	24	10.76
5	6.39	43	8.40	36	17.29	21	9.41	76	15.81	24	10.94
4	6.64	43	8.72	36	17.62	21	9.70	76	15.64	24	11.12
3	6.91	43	9.05	36	17.95	21	10.00	76	15.47	24	11.31
2	7.18	43	9.40	36	18.29	21	10.31	76	15.29	24	11.51
1	7.46	43	9.75	36	18.63	21	10.63	76	15.12	24	11.71
0	7.74	43	10.11	36	19.03	21	10.96	76	14.95	24	11.92

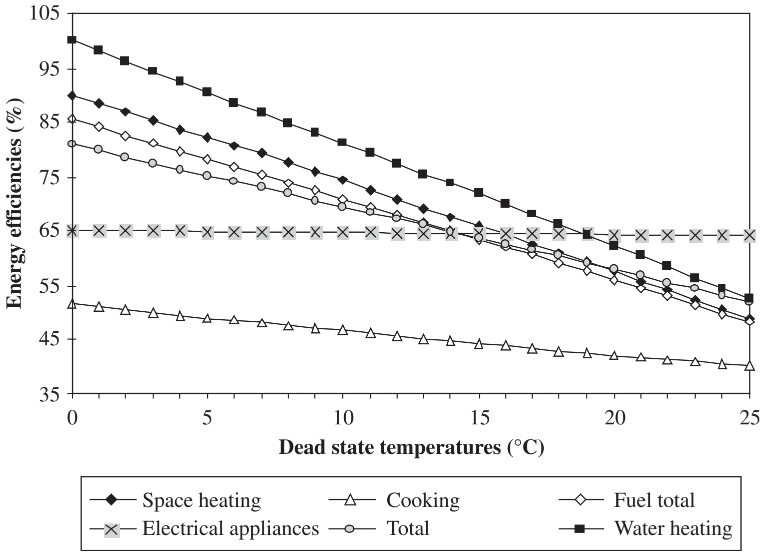

Fig. 10. Energy efficiencies of the Turkish residential–commercial sector at varying dead state temperatures from 0 to 25 °C.

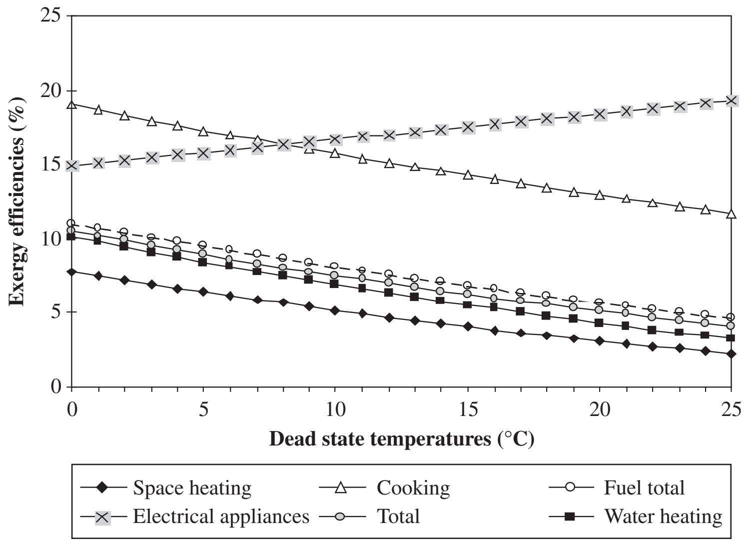

Fig. 11. Exergy efficiencies of the Turkish residential–commercial sector at varying dead state temperatures from 0 to 25 °C.

[62,63]. These results indicate the need of saving in the use of energy, and to improve habits of energy use in this sector and its sub sectors. The space heating, constitutes the biggest exergy loss, followed by the water heating and cooking activities in the TRCS. Through the

evaluation of the results given in Tables 7 and 8, it may be concluded that the TRCS has about equal and fairly high energy efficiencies, while it indicates a very poor performance in terms of its exergy efficiency values.

5. Conclusions

This study investigated the effect of varying dead state temperatures on the results of energy and exergy utilization efficiencies in the RCS. An illustrative example was given for demonstrating the energy and exergy efficiency variations based on the actual data of Turkey in 2003. The energy efficiency values for the TRCS were found to vary from 51.95 to 80.82% and the exergy efficiency values for that were obtained to range from 8.11 to 11. 92% at varying dead state temperatures from 25 to 0 °C. It may be concluded that the analyses reported here will provide the investigators with a better, quantitative grasp of the inefficiencies and their relative magnitudes in evaluating the energy utilization performance of countries.

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